Fisheries Research 216 (2019) 96–108

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

Human perceptions of, and adaptations to, shifting runoff cycles: A case-study of the Yellowstone River (Montana, USA)

Chase C. Lamborn[a,b], Jordan W. Smith[a,b,*]

[a] Institute of Outdoor Recreation and Tourism, 5215 Old Main Hill, Logan, UT 84322-5215, United States
[b] Department of Environment and Society, 5215 Old Main Hill, Logan, UT 84322-5215, United States

ARTICLE INFO

Handled by George A. Rose

Keywords:
Climate change
Proliferative kidney disease
Recreational angling
Fishing industry
Qualitative analysis

ABSTRACT

Throughout the western United States, researchers have started documenting a trend toward earlier runoff, lower in-stream flows, and warmer-than-average water temperatures. These 'drought-like' stream conditions often lead to negative ecological, economic, and social consequences. To gain a deeper understanding of these emerging impacts, we focused our investigation on the Yellowstone River, which experienced a major drought event in 2016. This drought lead to an outbreak of Proliferative Kidney Disease that killed approximately 10,000 fish and resulted in an emergency closure of 294.5 km of the river for 15 days. We conducted semi-structured, in-depth interviews with outfitters, guides, government researchers, and state fisheries biologists/managers working within the Yellowstone River watershed. Our work was guided by three objectives: 1) to determine if people perceive changes in the runoff cycle; 2) to identify the impacts of changing runoff; and 3) if impacts are occurring, to document what adaptations strategies are being used to address them. In our discussions, respondents described an earlier runoff, shorter and more intense runoff, and more interannual variability in runoff. The impacts respondents associated with these changes were: 1) increased uncertainty in yearly planning and fishing quality; 2) altered fishing quality; 3) changes in species distributions; 4) disease outbreaks; and 5) imposed fishing restrictions. Respondents also described the following adaptations to mitigate impacts: 1) altering catch-and-release practices; 2) temporally shifting trips; 3) spatially shifting trips; 4) drought anticipation; and 5) targeting warm water species.

1. Introduction

Hydrologic and thermal regimes are fundamentally important for aquatic ecosystems. The characteristics of a stream's hydrology is critical for the species that live within the system given its effects on water quality, energy flows, habitat, and biological interactions (Karr, 1991; Poff et al., 1997; Poff and Ward, 1989). In addition, stream temperature is vitally important for physiological processes of aquatic species (Pörtner et al., 2008; Pörtner and Farrell, 2008; Takasuka et al., 2007), fish growth (Neuheimer and Taggart, 2007), abundance (Ebersole et al., 2003; Sloat and Osterback, 2013), and distribution (Buisson et al., 2008). In short, changes to hydrology and temperature can have dramatic impacts to aquatic systems.

Throughout the western U.S., researchers have documented recent trends in stream runoff and temperature. These trends include earlier runoff, lower summer flows, and warmer water temperatures (Al-Chokhachy et al., 2017; Isaak et al., 2012; Leppi et al., 2012; Rood et al., 2005; Stewart et al., 2004, 2005), and some research has even identified an acceleration in these trends over the last 8–10 years (Leppi et al., 2012). The main driver of these changes is increased air temperature (Isaak et al., 2012; Leppi et al., 2012), with recent air temperatures being especially warmer than average during the winter and spring seasons (Dettinger and Cayan, 1995; Lettenmaier et al., 1994). With air temperatures expected to increase (Intergovernmental Panel on Climage Change, 2014), models predict large decreases in fresh, coldwater habitat, ultimately leading to decreases in coldwater species distribution and abundance (Jones et al., 2013; Lessard and Hayes, 2003; Wenger et al., 2011).

While recent research has documented trends toward lower than normal in-stream flows and warmer than average temperatures across the western U.S., researchers have only been able to speculate about how these changes will affect the diverse ecological *and* social components of a river system; most have just focused on the ecological components of a river system, such as fish (Al-Chokhachy et al., 2017; Isaak et al., 2012). These studies have provided valuable insights into how stream discharge, as well as stream temperatures, are changing.

* Corresponding author at: Institute of Outdoor Recreation and Tourism, 5215 Old Main Hill, Logan, UT 84322-5215, United States.
E-mail address: jordan.smith@usu.edu (J.W. Smith).

https://doi.org/10.1016/j.fishres.2019.04.005
Received 23 January 2019; Received in revised form 4 April 2019; Accepted 8 April 2019
0165-7836/ © 2019 Published by Elsevier B.V.

Given the consistent evidence presented in this line of work, social scientists can now begin to examine how changes in runoff affect the social components of river systems as well (Hunt et al., 2016).

Only a few investigations have documented how changes in hydrologic and thermal regimes will impact both ecological and social systems. Jones et al. (2013) modeled the potential biological and economic impacts of climate change on freshwater fisheries in the U.S. using different climate scenarios. The authors first modeled the biological impacts of climate change by mapping the current habitat for three thermal guilds: coldwater, warmwater, and rough. Under current greenhouse gas emissions, their model projected a 50% reduction in coldwater habitat by 2100. Lost coldwater habitat would result in coldwater species being replaced by fish species in the warm and rough guilds. The authors also modeled the economic impacts of this habitat shift, estimating a national economic loss of between $81 million and $6.4 billion by 2100, depending on the greenhouse gas emission scenario. Similarly, Ficke et al. (2007) outlined the many ways climate change can affect freshwater fisheries and the people that rely on them. They describe how climate change can impact water (i.e., increasing water temperatures, decreasing dissolved oxygen, increasing toxicity and pollutants, shifting hydrologic regimes, increasing hydrologic variability, etc.), how these changes will impact fish, and how impacts to fish will ultimately affect food availability and economies that rely on recreational and/or commercial fishing.

Given the scant amount of research investigating the social implications of altered hydrologic and thermal regimes—specifically the impacts to fish, fishing, and tourism—our investigation set out to document the implications for one specific river—the Yellowstone River in Montana, USA. Our work was guided by three objectives: 1) to determine if people perceive changes in the runoff cycle; 2) to identify the impacts of changing runoff; and 3) if impacts are occurring, to document what adaptations strategies are being used to address them.

2. Study area

We chose the Yellowstone River as our study area for four reasons. First, it is a large, well-known freshwater fishery that attracts many anglers and is home to outfitters and guides, fisheries biologists/managers, and others who may have an intimate knowledge of the Yellowstone River. A larger population of possible study participants increases the likelihood of obtaining a more diverse set of perceptions and responses. Second, the Yellowstone River is a long, free-flowing river that traverses a wide geographic and temperature range. This made it a good candidate for investigating the effects of river flow and temperature on changes in fish populations, the behavior of anglers, and the local fishing industry. The river stretches from Yellowstone Lake down to Billings, Montana, covering 397.5 km (Fig. 1). Third, the Yellowstone River has experienced multiple low-flow and warm-water events in the recent past (i.e., 2013, 2015, and 2016) (USGS Livingston, MT gauge station). The worst of these events occurred in 2016, when the Yellowstone River experienced a severe low- and warm-flow event and an outbreak of Proliferative Kidney Disease (PKD), which is caused by a parasite—*Tetracapsuloides bryosalmonea*—that affects fishes organs. After approximately 4000 fish were found dead, the Montana Department of Fish, Wildlife, and Parks closed a 294.5 km stretch of the Yellowstone to all recreational use—from Yellowstone National Park to Laurel, Montana (Opitz and Rhoten, 2017). Up to 10,000 Mountain Whitefish (*Prosopium williamsoni*) were estimated to have been killed by the disease during the outbreak in 2016 (Byron, 2016). The fourth and final reason we chose the Yellowstone River as our study location to investigate changes in fish populations, the behavior of anglers, and the impacts on local fishing industry was the unique opportunity to integrate documented shifts in temperature and runoff within the river (Al-Chokhachy et al., 2017) with data we gathered from our interviews.

The hydrology of the Yellowstone River is also important in helping frame and contextualize our findings. The flow of the Yellowstone River fluctuates widely through its annual runoff cycle. During the winter, the river has a relatively stable flow and snow accumulates in the mountains and around the river. During the spring (April and May), as temperatures increase and the snow melts, in-stream flows increase and the river approaches peak-flow. The Yellowstone River generally reaches peak-flow in early- to mid-June. After the peak-flow event, water levels begin a gradual decline throughout the summer, usually reaching the lowest and warmest levels in August or early-September, which is generally when coldwater fish species are under the greatest amount of temperature-related stress. During the fall, air and water temperatures decline and the river returns to its base-flow. Rain events can affect the river with small spikes in flow, but the annual runoff cycle is the predominant flow regulator.

Lastly, it would benefit readers to know how important recreational angling is to Montana and the economy surrounding the Yellowstone River. In 2015, anglers spent a total of $128.6 million USD in the state of Montana (Sage, 2016). Much of the upper Yellowstone River, and about half of our study area is located in Park County, MT. In 2013, anglers spent $69.9 million USD in Park County alone, and nearly 40% of this spending is on outfitters and guides (Sage, 2016).

3. Methods

We started our investigation by conducting semi-structured interviews with experienced outfitters and guides who had consistent and long-term exposure to the Yellowstone River and its ecological processes. We chose experienced outfitters and guides because they are likely to: 1) have an intimate knowledge of the Yellowstone River; 2) be sensitive to both ecological and social changes that affect the river; and 3) have knowledge of, and be economically affected by, ecological events and management decisions (e.g., the river closure in response to the PKD outbreak in 2016). However, during conversations with outfitters and guides, we would regularly hear them say, 'if you want to know the details about that, you are going to have to talk with [insert name] from Montana Fish, Wildlife and Parks.' These comments lead us to broaden our sample to include state fisheries biologists/managers and government researchers whose work has specifically focused on the Yellowstone River watershed. It became clear that widening our scope added new perspectives to the changes, challenges, and adaptations we were interested in investigating. It also became clear the information and perspectives we were gathering from these people was largely unavailable to the public because it involved personal experience and/or was unpublished. Our main goal was to detail how shifting runoff is affecting this social-ecological system, and it became clear we needed to incorporate the knowledge and perspectives of more than just outfitters and guides to do that. This is why we chose to include state fisheries biologists/managers and government researchers in our sample.

Our initial phase of data collection started by searching the internet for outfitters and guides who operate on the Yellowstone River. From this search, a list of contacts was created. Additional study participants were identified through snowball sampling methods. Through these method, we obtained additional contacts which included outfitters, guides, state fisheries biologists/managers, and government researchers. While all of our respondents provided additional people for us to contact, we only contacted those references that fit within the scope of our study, meaning they had detailed knowledge of, and frequent interaction with, the ecological processes of the Yellowstone River.

An interview guide of open-ended questions was used to direct conversations. The interviews were structured around three sets of questions related to: 1) perceptions of hydrologic and thermal shifts on the Yellowstone River; 2) noticeable impacts of perceived shifts; and 3) adaptive responses that have, or are, being taken to address these impacts. To avoid response bias, all conversations were focused specifically on stream runoff/temperature and drought events—which we defined as extreme low- and warm-flow events. Additionally, we never

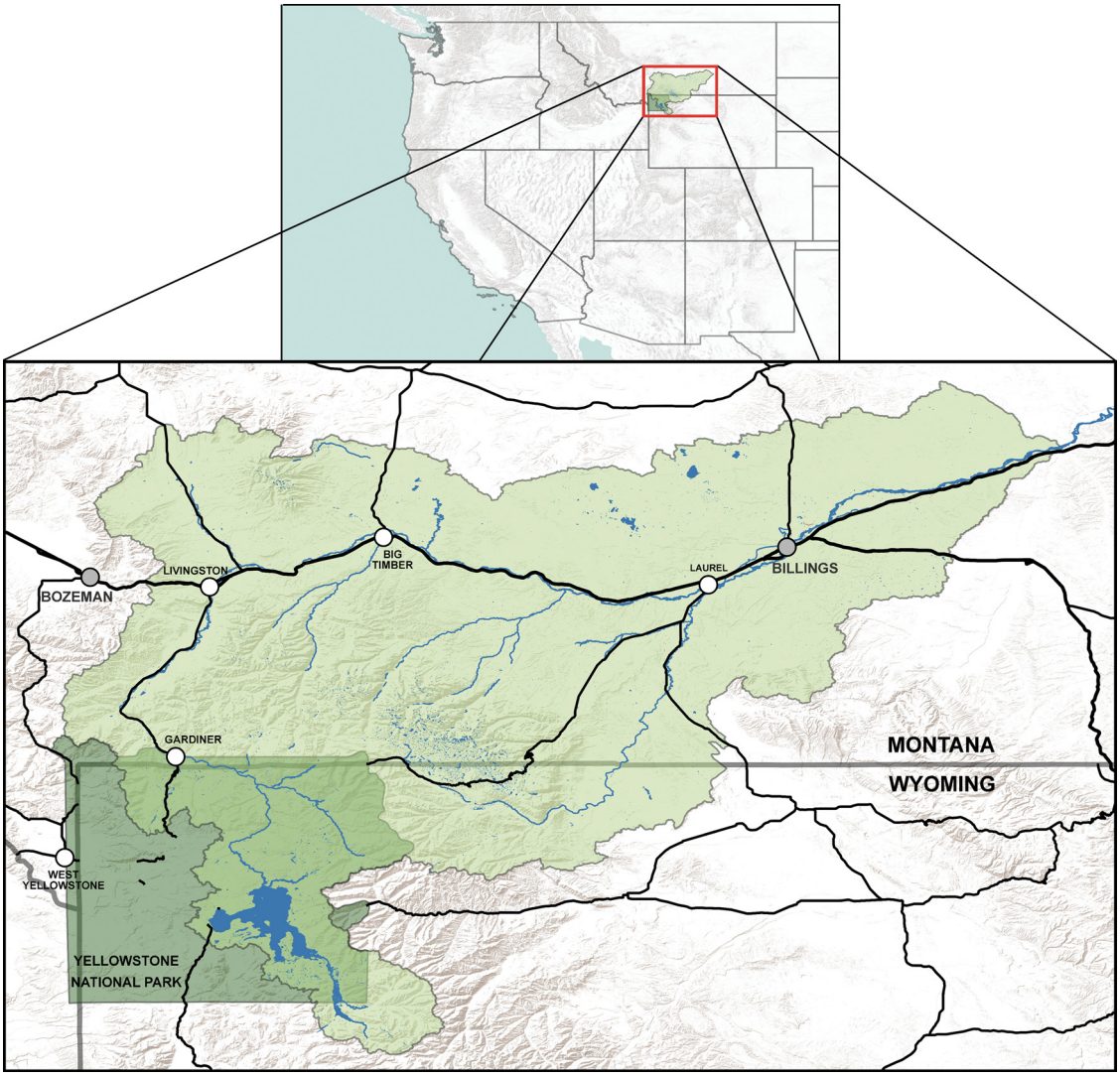

Fig. 1. They Yellowstone River Watershed.

mentioned the terms “climate change” or “global warming” during the interviews. However, most interviewees brought up climate change, and discussions about climate change generally proceeded from that point. All data collection methods were approved by Utah State University’s Institutional Review Board.

A total of 12 interviews were completed: 7 outfitter/guides; 3 fisheries biologists/managers; and 2 researchers. Only one person we contacted did not agree to participate because they did not feel they had enough experience to inform our study. Data collection ceased when interviewees provided no new contacts. Given the lack of new suggestions for potential interviewees, we are confident we reached the majority of potential participants fitting within the scope of our target population. While the overall number of participants may seem low, we are also confident in the breadth and depth of our data because toward the end of data collection, new interviewees did not yield additional information, indicating we had reached theoretical saturation (Corbin and Strauss, 2008).

Interviews were conducted over the phone, recorded with the permission of the respondent, transcribed verbatim, and uploaded into the software NVivo, which was used for all data analysis. The interviews ranged from 44 to 128 min in length, with an average duration of 71 min. Because the focus of this study was long-term trends, we were particularly interested in interviewing individuals who had the greatest amount of experience with the Yellowstone River. Years of experience, which is the number of years a respondent had directly worked on the Yellowstone River, ranged from 7 to 57 years, with a mean of 21 years. Fisheries biologists and researchers tended to have the fewest years of direct contact with the river, and outfitters and guides had the most.

Data generated through the interviews were analyzed using an inductive coding and thematic analysis approach (Corbin and Strauss, 2008). An inductive approach allowed us to freely explore the complex and evolving relationships between the economic, environmental, and social factors of the Yellowstone River. Our analysis blended qualitative (i.e., responses from interviewees) and quantitative research (i.e., outside, peer-reviewed data). We attempted to tie the inferences we gained from the interviews back to published research, ultimately connecting lived experiences with documented ecological processes and changes.

Our analysis of the interview data followed a phenomenological approach given our focus was on a group of individuals who have a common lived experience with a phenomenon (i.e., changes in hydrological regimes and low- and warm-flow events) (Creswell, 2013). Phenomenological studies utilize varied sources of data to describe the phenomenon and its ramifications (Creswell, 2013; Moustakas, 1994), which we were able to do by connecting our interview data to published, peer-reviewed literature (e.g., Al-Chokhachy et al., 2017) in the discussion. This approach enabled us to accomplish three things: 1) corroborate lived experiences with scientifically documented phenomenon; 2) describe scientifically documented phenomenon through the

Table 1
Higher- and lower-level categories/themes generated from the analysis.

Higher-level category/theme	Lower-level category/theme
Observed changes in hydrology	Earlier runoff
	Shorter and more intense runoff
	Increased annual variability
Impacts	
Uncertainty	Uncertainty in booking guided trips
	Warmer water in late-summer
Altered fishing conditions	Tougher fishing conditions
	Increased fishing pressure
	Changes in aquatic insect life
Changes in species distributions	Decreased range of cutthroat trout
	Increased range of smallmouth bass
Disease outbreaks	Whitefish die-off
	Limited geographic scope
	Large social and economic impacts
Imposed fishing regulations	Hoot-owl regulations
	2016 full river closure
Adaptations	
	Altering catch-and-release practices
	Temporal shifts
	Spatial shifts
	Drought anticipation
	Targeting warm-water species

lens of people's lived experiences (including managers and researchers); and 3) expand our knowledge of the impacts of shifting stream temperature and hydrology.

Following the data analysis process outlined by Corbin and Strauss (2008), data were first coded into high-level categories. This was done by grouping data into general descriptive categories, such as "runoff," "water temperatures," "fish," "adaptations," etc. Once all the data were categorized, we returned to each high-level category and searched for additional nuance and structure within the data to create subthemes. For example, within the high-level "fish" category, subthemes were "whitefish," "smallmouth bass," "cutthroat," "distribution," "changes," etc. Once all data were organized into higher- and lower-level categories/themes, we iteratively reviewed the data, testing and refining concepts, identifying connections between themes through axial coding, writing memos, and building themes into narratives.

4. Results

The final set of higher- and lower-level categories/themes generated from the interview data are presented in Table 1. We first describe how respondents perceived hydrologic and thermal shifts on the Yellowstone River. We then discuss the impacts of these shifts. Finally, we present the adaptation strategies used to address these challenges.

4.1. Observed changes in hydrology

During our interviews, we asked respondents if they had noticed any changes in the runoff cycle over the time they have spent in the Yellowstone River watershed. Two outfitters and guides indicated they have not been able to perceive any long-term changes, stating that runoff is just "cyclical" with large and small runoff years. One challenge with being able to perceive a long-term trend is the highly variable nature of the runoff cycle, and without critically analyzing runoff data, or having a long timeframe to refer to, seeing long-term changes can be very difficult. One respondent illustrated this by saying,

> These things are slow enough that they are hard to perceive… I have been so intensely focused on [my business] from day to day that I haven't really noticed a big difference. Though again, if you talk to people who have been here for 50 years they will say that winters used to be so much worse and start sooner and end later. So I do believe that it is happening in the long-term. But again, there is so much variation that it is hard to perceive those long-term trends.

All other respondents had perceived, or were at least aware of long-term changes in the runoff cycle. The three main changes they identified were: 1) *earlier runoff*; 2) *shorter and more intense runoff*; and 3) *increased annual variability* (i.e., drought and flood years). One outfitter who was not very experienced on the Yellowstone River relative to the other outfitters and guides we interviewed, noted: "Thirteen years of experience makes the longer-term trends harder to spot, but certainly I have read that runoff is tending to start earlier and end earlier, and that would fit with my limited experience." Another outfitter who had many years of experience working on the Yellowstone River said,

> When I first went to work for the fly shop here, the story I used to tell is just so much different than what I see now…I would say that somewhere around the 4th of July is when the Yellowstone would usually start to be clear enough…that we could start fishing…Now we have seen a lot of years where that early July clearing is more like the 25th of June.

Historically, fishing before July 4th was almost unheard of, as one outfitter said, "You can talk to the old-timers and they say, 'Yeah, we never used to fish the Yellowstone before the 4th of July.'" However, in recent years, fishing before July 4th is not uncommon, unless there is a big snow year.

Respondents not only described an earlier runoff cycle, they also described how the overall cycle has become *shorter and more intense*. For example, one outfitter said,

> I think [runoff] has gotten a lot shorter, and at times it can be a lot more intense actually. It seems like the intensity is a shorter lifespan…It gets really high for a very short period of time and drops back down or moderates… It seems to be starting sooner and not lasting as long. Unless we have a really big snowpack.

Beyond shifting runoff cycles, some respondents also said river conditions have become *more variable from year to year*. One outfitter illustrated this by saying,

> You know, going on the notion that weather is just getting more extreme in both directions. The general trend will be toward earlier fishing, but we will also have some really nasty winters, and possibly some years where the runoff lasts longer than usual…there are anomalies, like 2011… [we] weren't able to get on the river until almost the beginning of August because of a very heavy snow year.

Speaking of long-term changes in variability, and using the year 1988, the year of the large wildfire in Yellowstone National Park as a reference, one outfitter said,

> I think we have had more years with less snowpack since…[than we did] before 1988. We certainly had light years before and heavier years before, don't get me wrong on that, [but] I have seen more extremely high crests [in runoff] since 1988 than I have experienced in my [30 years of] experience prior to 1988.

This outfitter has observed two changes, which are, on average, less snowpack and more extremely high crests in runoff. They also attributed a portion of these changes to the change in forest canopy since the large fire.

Overall, some outfitters and guides did not perceive long-term changes in the Yellowstone River's runoff cycle, and called any variation "cyclical." The majority of respondents did perceive, or were aware of long-term changes, which were specifically an earlier runoff cycle, changes in runoff distribution, and annual increased variability. An important finding is that even the respondents who did not perceive long-term trends in runoff later described the impacts they have felt from recent low-flow events. These respondents also described the adaptation strategies they have used to manage the impacts. Therefore,

even though respondents may not have perceived recent events as long-term trends, they were still reacting to the associated impacts of recent shifts in runoff.

4.2. Impacts from shifting hydrology on the Yellowstone River

4.2.1. Uncertainty

As the runoff cycle shifts earlier in the season, less water becomes available during the hottest part of the summer. The combination of low water volume and high air temperatures result in high water temperature (Isaak et al., 2012). The Yellowstone River has experienced some recent warm water years in 2013, 2015, and 2016 (USGS Livingston, MT gauge station). The summer of 2016 was especially severe, leading Montana Fish, Wildlife, and Parks to implement restricted fishing hours. These restricted hours, termed 'hoot-owl' restrictions, prohibit fishing from 2:00pm to Midnight. They are implemented when water temperatures reach or exceed 73 °F (22.7 °C) for three consecutive days. The PKD outbreak occurred in August of that year, leading to the complete closure of the river and much of the watershed.

There has always been an aspect of uncertainty regarding river and fishing conditions in the outfitting and guiding industry; however, outfitters and guides expressed that the increased variability of runoff magnitude and timing have created additional *uncertainty with regards to booking fishing trips*. During a drought year, low and warm river conditions in August can result in poor fishing conditions and possibly fishing restrictions. If there are multiple drought years in a row, followed by a flood year, outfitters and guides need to get the word out to potential clients to change their expectations about when fishing conditions are best. For example, one outfitter said,

> This year we actually had pretty good water flows and temperatures, but because of the troubles we have had in the previous couple years, people are a little gun-shy about making long-term plans for August on the Yellowstone.

Earlier runoff creates a high probability for low and warm water, which creates poor fishing conditions in August, and the possibly of river restrictions or closures. Increased variability from year to year also creates booking challenges, and great efforts are made by outfitters and guides to inform potential clients of each year's conditions so clients plan their summer fishing trips accordingly. Outfitters and guides described the need to be cautious booking trips in August during these years because low and warm water conditions may impact the quality of fishing. One respondent said: "the past couple of years August has been tough for us, particularly for the fish because we have had low warm water."

Fisheries biologists and managers have also experienced troubles with shifting runoff when conducting their annual fish population estimates. One fisheries biologist said the changes in runoff have affected their ability to conduct mark and recapture population estimates in the spring before peak-runoff. Over his time working on the Yellowstone, it was common to not have ideal river conditions to obtain a population estimate. However, he noticed that prior to 1993 population estimates were obtained every year, and the frequency of missed population estimates increased since 1993. He brought this question up with his colleagues, and the answer he received was that the area used to get more "low-land runoff…in March when the snow melts from 4000 to 6000 feet of elevation (1.2 - 1.8 km) [that] would bring the river up a little bit before the mountain snow comes off in May and June." He also said,

> The ground is mostly bare from 000 to 5000 feet [1.2–4000 to 5000 feet (1.2 - 1.5 km) now, and so we don't get that pulse of low-land snowmelt in March that we used to. Some years we just can't [get a population estimate]. We look at the flow and we're waiting… for about 2000 CFS on the gauge or we just can't effectively shock. Some years we wait and wait and then it goes from 2000 to 10,000 CFS and [we are unable to conduct the survey]… you need [at least] 10 days where you have enough water but not too much. Some years that just doesn't happen. You'll get an 80-degree (F) day and here [the runoff] comes. It used to be a little more moderated by that lowland snow when –70-degrees [F; 15.5°–60 to 70-degrees (F; 15.5° - 21 °C) would melt your lowland snow but not that mountain snow so it wouldn't come all at once.

4.2.2. Altered fishing conditions

The impacts from low and warm flows usually occur in August. As water temperatures approach or exceed 21 °C (70 °F), many outfitters and guides said *fishing slowed way down*. Speaking about how water temperatures affect fishing, one outfitter said, "the fishing does suffer. The fish are just not as eager to eat when they are getting into a stressful level of water temperatures." Another outfitter repeated, "the real hot summers and dry water years… That makes the fishing challenging if I was to say one thing. I mean tough fishing conditions." In addition to the tougher fishing conditions that come with low and warm water conditions, respondents expressed two other factors that have made fishing more challenging in recent years, which were *increased fishing pressure* and *changes in aquatic insect life*. Although increased fishing pressure is outside of the scope of shifting runoff, and the connection between aquatic insect life and shifting runoff is not fully understood in this context, we chose to include these two themes because they are part of the current experience on the Yellowstone River and have implications for the main focus of this study.

Increased fishing pressure was often cited as a long-term issue that has made fishing more difficult. Overall, more recreationists on the water, both anglers and non-anglers, with more artificial flies and lures in the water, and more fish being caught has dramatically changed the experience of fishing on the Yellowstone.

To be clear, many people said the Yellowstone is a great fishery, and they still have very good fishing days, but those days are fewer and farther apart. It was also said that to have a good day, a person needs to be a much better angler now than in the past. When reflecting on how fishing has changed on the Yellowstone, one outfitter said,

> I will say that when I first moved here, it was very uncrowded, and to catch fish, man, you could put on any big fluffy dry fly you wanted and float down the river and cast at either bank, or wherever you wanted to cast, and it was going to work. You were going to catch fish doing it. Now, with the pressure that is out there, you do have to be a better angler.

Another outfitter touched on both increased use and changes in insect life as being reasons why fishing has become more difficult on the Yellowstone.

> I think [increased use] has made the fish tougher to catch. More pressure upon them, more flies on the water constantly floating by them, they are a lot more educated. It's hard to say for a fish that has a brain the size of a pea to be educated, but they are harder to catch. Their feeding habits have changed a little bit. It used to be that just fishing a dry fly all day, start to finish, you could do well. If you knew where and how to fish the dry fly, you would be catching trout all day, and now it's not always the case. The only thing I can think of is that it is due to, some of it may be biological. I do think that the hatches might be a little bit less, or shorter, than they seemed to be in the past, but a lot of it could be due to the pressure too. So, yeah, the fishing has changed.

Many outfitters and guides said hatches—the time when aquatic insects transition from their nymph phase to their terrestrial phase—-have changed over the years, which has made fishing more difficult. When asking an outfitter if the changes he had seen in the runoff cycle have affected the fish and the quality of fishing, he responded by saying,

> I have seen more of an impact on our insect life. It is just drastically different from what it was when I moved [to the Yellowstone]. I would say there are definitely less bugs and it definitely seems to change. Dry fly fishing is not as reliable as it used to be…. In the springtime when we used to have good insect hatches, Baetis, March Browns, Mother's Day Caddis, all those hatches barely happen anymore…I wouldn't say they are gone, but they don't happen in the numbers that they used to.

We asked state fisheries biologist/managers if they were aware of these changes and if they had any data to support these observations. One biologist, from his personal experience, described how hatches have changed, and how the dry fly fishing has suffered because of it. He also described how the condition factor—a metric that uses a fish's length and weight to quantify their health—has not changed, which indicates that the fish are getting enough food. Therefore, these changes seem to be affecting the quality of fishing more than the health of the fish themselves.

We asked another biologist if he had, or was aware of, any data that could illuminate what is going on with the Yellowstone's aquatic insects, and he said:

> We don't…visually, and I'm guessing that you have probably heard this from some of the outfitters and guides, hatches and things have certainly changed through time. Most of what I hear is in terms of abundance, and I would tend to agree. Timing seems to be off a little bit with some of those, too. Mother's Day Caddis is not on Mother's Day anymore, and we think that's because of the change in flow regimes. A lot of times, Mother's Day can be a pretty good runoff, and 20 years ago the runoff around Mother's Day was just getting started. We've had those kinds of shifts.

When discussing all of these impacts, and how things have changed over time, many respondents explained that yes, things have changed, and those changes do have an impact and are concerning, but the fishing and the overall health of fish in the Yellowstone River watershed is still good. However, there was a strong consensus that fishing on the Yellowstone has changed and become more difficult, due to three predominant factors. The first factor, and probably the most temporary in duration, is low and warm water conditions that are becoming more frequent in August. Secondly, the Yellowstone River is receiving much more use now than it did in the past. Lastly, the aquatic insect life has changed on the Yellowstone River, which has seemed to make all fishing, but specifically the dry fly fishing, more difficult. Respondents also describe how these three factors compound on each other and make fishing more difficult. For example, one outfitter said,

> Well, two things happen… 1) the fish are less active [in warm water]; we catch fewer fish per unit time… You also get into situations where there are low-clear waters, and you still have high sun, [which] means you have 2) a lot of spooky fish that have already been caught… so they are just plain less likely to bite.

4.2.3. Changing species distributions

In addition to altered fishing conditions, respondents also described *changes in species distributions* that were associated with changes in runoff and warmer water. The two changes in species distribution identified by respondents were: 1) *decreased range of Yellowstone cutthroat trout* (*Oncorhynchus clarkii bouvieri*) and 2) *increased range of smallmouth bass* (*Micropterus dolomieu*). On the upper Yellowstone, the Yellowstone cutthroat trout is the only native sport fish. However, there are introduced, non-native species that are critically important sport fish as well, such as the rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*), both of which are coldwater sport fish. On the lower Yellowstone, where the water is warmer, there are non-native smallmouth bass (*Micropterus dolomieu*) that are also an important sport fish.

In the last 30 years, there has been a significant decline in Yellowstone cutthroat trout. Describing how much the cutthroat population has declined, a fisheries biologist said that a section of river near Springdale, MT,

> [Historically] had around 200–250 cutthroat per mile (1.6 km), but by the time I got here and started my career, within the first 5 years we were lucky to catch 50 cutthroat total in that section, so pretty big drop in abundance there. Through time, if you go back and look at work that my predecessors did compared to what we are seeing now, there has been that gradual decline in cutthroat throughout the whole basin, but we see it in a much more significant rate in the lower end of the river.

Respondents attributed multiple factors to the decline of Yellowstone cutthroat, including harvesting issues in the 1970s and 1980s (which were later resolved with catch-and-release ethics), competition between cutthroat and non-native gamefish like rainbow and brown trout, increasing stream temperatures, and crossbreeding between cutthroat and rainbow trout. Crossbreeding might not appear to be directly linked to changes in runoff, but rainbow trout spawn on the ascending side of runoff and cutthroat spawn on the descending side (Muhlfeld et al., 2009), and changes in runoff have led to new overlaps in spawn timing. To further explain how this relates to a compressed runoff cycle, a biologist said,

> We've done research and know that in tributaries where [rainbow trout and Yellowstone cutthroat trout] spawn…they are using the same areas. Not only in the same tributaries, but they are in the same areas, so as we compress [the runoff cycle] we are increasing the risk of potential to see an increase in hybridization.

Overall, respondents expressed concern about the current condition of the Yellowstone cutthroat trout. Outfitters and guides seemed less concerned about the Yellowstone cutthroat specifically, but they did have great concern for wild trout as a whole. State fisheries biologists and managers expressed a great deal of concern for preserving the Yellowstone cutthroat trout, as they are performing a difficult balancing act between native species preservation and managing a high quality fishery.

Smallmouth bass are also increasing their range in the Yellowstone River; as one outfitter said, "[It] seems like there are more and more [smallmouth bass] every year. I caught more smallmouth bass in the sections I float this year than I ever have." The exact reason for their expansion is unknown, but a respondent who studies smallmouth bass in the Yellowstone River provided two of the leading hypotheses, which are: 1) warmer than average water temperatures are expanding their habitat; and 2) they have not yet reached the capacity of the environment in which they were introduced. This researcher continued by saying,

> There is growing evidence throughout the West that there is currently a lot of cool-water and warm-water fish that are expanding their ranges as stream temperatures warm, amongst other drivers. One of those cool-water fishes that has been making some pretty well documented expansions are smallmouth bass.

We asked a fisheries biologist if smallmouth bass were having an effect on the Yellowstone River's trout population, and he said,

> We haven't seen anything, especially up here. The report of abundance is so low on bass that there really hasn't been much of an effect here. As you move down river, there's quite a bit of overlap [between bass and trout], and as far as I know those guys aren't seeing any indication or trends at this point. They haven't seen an effect.

Among the outfitter and guide community, there are concerns about smallmouth bass impacting the trout fishery, as one outfitter said regarding the expanding range of smallmouth bass,

> [It is] a big concern…The state biologists are tracking them, and they have noticed an up-river trend in their abundance…I have heard from people back East and other areas where smallmouth have taken over trout rivers, and they are known as voracious predators, and have had a big effect, at least anecdotally.

Even though there are concerns among outfitters and guides, fisheries biologists/managers did not seem highly concerned about smallmouth bass having a large impact on the trout fishery at this point. One respondent, when asked about the impact of smallmouth bass on trout in the Yellowstone, replied, "The majority of the [trout] population is rearing further upstream, bass aren't there yet… We don't have any data yet suggesting that they [should be a] major concern." While respondents perceived the threat of smallmouth bass differently, *changing species distributions*, especially the decreasing range of Yellowstone cutthroat trout, remained a concern.

4.2.4. Disease outbreaks

While its cause remains unclear, the outbreak of PKD in 2016 was a shocking event for those who witnessed it. One outfitter described floating down the river, emphasizing, "you literally [saw] dead fish pretty much all the time." Yet the long-term economic impacts of the PKD outbreak were minimized because the outbreak had the largest impact on Mountain Whitefish (*Prosopium williamsoni*), which are not a primary sport fish in the Yellowstone River. Respondents speculated that if PKD had infected and killed more trout, the social and economic impacts may have been much more severe and long-lasting. The year after the outbreak, respondents explained it was nearly back to "business as usual," though there were some changes in how people perceived the Yellowstone River, leading to decreased bookings in August 2017.

Determining the overall impact of the PKD outbreak is difficult; however, there are a few things that are known. The most apparent is that *the mortality caused by PKD overwhelmingly affected a very abundant population of whitefish.* As one biologist put it, "The number of whitefish [where the outbreak occurred] is really incredible. When you turn the electricity on [when electrofishing for our population estimates] your boat is surrounded by 20–50 whitefish all the time." When speaking with outfitters and guides about their 2017 fishing season—the year after the outbreak—they said they did not notice any changes in the whitefish population, and they still caught them regularly despite the previous outbreak.

The second thing we know is that fish mortality attributed to PKD was *confined to a fairly small geographic region*. The section of the Yellowstone River below the town of Emigrant, Montana, suffered the most severe impacts, with the highest mortality levels spanning a distance of only 12.9 km. Lastly, despite the abundance of whitefish and the limited geographic range of the outbreak, the management response to PKD was large and had a significant *social and economic impact*. For example, as one guide described impacts to the river translated to impacts in the community, stating, "[When] the entire river is closed like last year, some of the best restaurants in town were just dead. The hotels were dead." Some of the outfitters and guides that were, for various reasons, unable to operate in areas outside of the closure suffered significant financial losses, given that summer is a short window in which they make the majority of their revenue for the year.

Because the outbreak occurred during a severe drought event, it would be easy to assume that drought conditions lead to PKD outbreaks; however, this is not necessarily the case. One respondent who studies PKD said, "Drought conditions alone don't cause the disease, but they can exacerbate the impacts of the disease." He explains,

> So far, every river we have collected healthy fish from in Montana, we have found evidence of the parasite. Now, we have a lot of rivers that in 2016 had comparable conditions as the Yellowstone, yet no one saw 10,000 dead fish. We have also documented now, through our archive samples, that the PKD parasite has been present in this system since at least 2011… The Big Hole, if you know it well, [experiences stressful conditions] every year with dewatering as a function of both weather/climate and irrigation. Every year it sees conditions that are likely much more stressful than what the Yellowstone saw in 2016… Yet, no giant fish kills.

As alluded to above, not only is PKD widespread in Montana, but it has also been there much longer than previously thought, leading researchers to hypothesize the parasite causing PKD is native to the Yellowstone River. However, without historical water samples, researchers do not have the data to fully confirm it. With the parasite that causes PKD being widespread, and many rivers where it is present seeing regularly occurring drought conditions with no outbreak, predicting a future outbreak at this point is nearly impossible because the triggers for the outbreak are still not fully understood.

At the time of the outbreak, little was known about the parasite, leading Montana Fish, Wildlife, and Parks to implement extreme management measures to reduce fish stress and contain the infection. Now knowing that many rivers in the region contain the parasite that causes PKD, and have for some time, fisheries biologist/managers would most likely respond much differently to a future outbreak.

Perhaps what is most surprising is the impacts of the closure had a greater social and economic impact than the outbreak itself. The river closure was an extreme measure, and would probably not be implemented again. All outfitters and guides in our study were supportive of the actions taken by Montana Fish, Wildlife, and Parks to protect the Yellowstone River, given the information they had at the time.

4.2.5. Imposed fishing regulations

The full river closure in 2016 was a unique event; however, there are other regulations, such as the aforementioned hoot-owl regulations, that are implemented to reduce the stress placed on fish during warmer than average water temperatures. Hoot-owl regulations are more commonly implemented, and outfitters and guides described being able to work around them and maintain business. However, when discussing the PKD outbreak with outfitters and guides, many discussed the impacts to their businesses and the area's economy. One outfitter compared the difference between hoot-owl regulations and the 2016 river closure by saying,

> The hoot-owls aren't terrible because people are still out here. Everyone just quits early and they are still out at the hotels and everything like that. They are still going to dinner. I don't know if hoot-owls hurt us that much. Probably a little bit because people hear that there is a hoot-owl, and maybe they say 'let's not go to Montana next week.' But usually people plan months ahead of time, and they are going anyway. Where like if the entire river is closed like last year, some of the best restaurants in town were just dead. The hotels were dead. That was different.

While outfitters and guides were directly impacted by the river closure, the closure had differing impacts within communities. As mentioned in the above quote, businesses that could not move, such as restaurants and hotels, were "dead" because of the river closure and people not coming to the area. In addition to restaurants and hotels being impacted, so were other businesses, as one outfitter who owns a fly shop said,

> The raft companies for instance, their season was simply over. By the time the river got reopened at all, they had to turn their crews loose and simply shut down because they couldn't deal with an indeterminate timeframe, so they got hurt much more significantly than I did.

Fly shops were also impacted by the closure, and depending on how deep within the closure the fly shop was, the greater the impact. For example, one outfitter/fly shop owner from the middle of the closure

said,

> A leading indicator of traffic through the store that we use a lot is fishing license sales. On a general basis, [fishing license] sales for us are multiple thousands [of dollars] a week. When it goes from that to less than 100 dollars when the river is closed, it lets you know how many people are not walking through the doors.

Those with the ability to move out of the closure and guide in other waters were better able to buffer their losses, though they too felt the impacts of management actions.

Drought conditions on the Yellowstone River, as well as management actions aimed at reducing resource stress on fish, can lead to stress on the region's tourism industry. Different management actions, such as hoot-owl regulations versus river closures, created different community impacts. Communities have seemingly adapted well to hoot-owl regulations because people are still visiting. Outfitters and guides can start trips earlier in the day, and other businesses, such as restaurants and hotels, can still capture revenue from those still coming to the region to fish and recreate. However, management actions such as full river closures have a much greater impact on businesses in the tourism industry.

4.3. Adaptation strategies

Interviewees revealed five strategies they often use to adapt to changes in the runoff cycle, including: 1) *altering catch-and-release practices*; 2) *temporally shifting trips*; 3) *spatially shifting trips*; 4) *drought anticipation*; and 5) targeting *warm-water species*. No single adaptation strategy is perfect, and many outfitters and guides used a combination of strategies.

As noted above, outfitters and guides found fishing becomes more difficult when water temperatures exceed the normal range for trout. In addition, fish that are caught in high water temperatures and then released have an increased probability of mortality (Bartholomew and Bohnsack, 2005). Most outfitters and guides still fish during low and warm flows, but when doing so, many expressed great concern for the resource and the fish. For example, one outfitter said, "When the river gets low and warm… it is one of those things, that if you go float the river you are worried about every fish you catch…" Outfitters and guides know that there is a certain amount of mortality associated with catch-and-release fishing, but they also know that higher water temperatures increases the likelihood of mortality,

> As you know, there is going to be a certain amount of mortality no matter what you do in any kind of conditions, but as the water temperature goes up then the likelihood of the fish dying probably increases and there is a greater percentage of mortality. We are trying to mitigate that as best as we can with proper practices and procedures.

To reduce stress on fish during drought conditions, respondents frequently described *altering their catch-and-release practices.* The strategies they mentioned were using stronger tippet (i.e., fishing line), reeling in fish quickly so they do not reach complete exhaustion, keeping them in the water, and releasing them quickly.

Outfitters and guides also use other strategies to reduce their impacts during drought conditions. These strategies can be categorized into *temporal and spatial adaptation*. *Temporal adaptation* includes self-imposed hoot-owl regulations, which is where a guide changes their own guiding hours before the state of Montana makes it mandatory. This means a guide will take their client fishing from dawn to around 2 pm, skipping the hottest and most stressful part of the day for fish. One outfitter summarized the strategy simply, saying to "change the hours, you know, like shift the day so we are starting earlier."

There is also *spatial adaptation*, which is generally the process of fishing in cooler water. During low and warm flows, one outfitter said he tries to chase cooler water,

> [We will do] an early morning float and get off the river pretty early, and then go fish a small mountain stream in the afternoon. [I] just try to maximize places where we are going to be dealing with reasonable water temperatures in the high mountain streams as long as they don't get dewatered completely in a drought year… It is a good change of pace in the day and just another way you can work around water conditions if they get challenging on the other rivers…. Another local thing, again, [is] that we have the spring creeks coming in just above town… the main thing is to try to avoid [high water temperatures].

Drought anticipation is another temporal strategy that includes avoiding fishing during the hottest parts of the year, and trying to schedule trips when water conditions are going to be less stressful for fish. This could still mean booking trips for August, but checking the snowpack and waiting to see what conditions are going to be like before doing so. For example, when dealing with poor snowpack, one outfitter said, "I just tend not to push my August calendar, and when folks inquire about it I just usually tell them to hang on until we have some idea [of what conditions are going to be like]." Outfitters and guides are not the only ones to respond like this, as clients are also starting to avoid August given the poor conditions in previous years. For example, one outfitter said that lately "August isn't as popular with booking… and I have certainly seen that with my own clientele."

Another adaptation strategy is *targeting warm-water species*, such as smallmouth bass and/or carp when temperatures get really high. During periods when temperatures are too high for quality trout fishing, and there is a high probability that released trout will die, outfitters and guides instead target warm-water species. One outfitter said there are a "handful" of guides that have started to take advantage of these opportunities,

> In the last few years…every time they can talk someone into going carp fishing they do that instead of going trout fishing if it's mid-July and August when a lot of times the conditions aren't that great for trout fishing anyway.

However, many outfitters and guides expressed this is not a very popular strategy because there is much less demand from clients.

5. Discussion

The goal of this study was to explore how shifting runoff cycles affect the broader components of a river system, including the human populations who benefit from the services provided by that river. Specifically, we had three goals: 1) to determine if people perceive changes in the runoff cycle; 2) to identify impacts of changing runoff; and 3) if impacts are occurring, to identify what adaptations strategies are being used to mitigate them.

To answer these three questions, we conducted semi-structured interviews with outfitters, guides, fisheries biologists, and researchers. Through these efforts we gained a better understanding of individuals' perceptions of changing runoff; we also identified a variety of ways shifting runoff cycles have and are affecting river ecology and use. The data also revealed a variety of adaptation strategies used by outfitters and guides to combat these changes. Each section below outlines our major findings, how they fit within existing literature, and a discussion about their implications.

5.1. Question 1: perceptions of changing runoff

Most of our respondents perceived long-term changes in the Yellowstone River's runoff cycle. The changes respondents discussed were: 1) earlier runoff; 2) shorter and more intense runoff; and 3) increased annual variability (i.e., drought and flood years). Studies conducted throughout the western United States have shown strong evidence that supports respondent observations.

With regards to an earlier runoff cycle, Al-Chokhachy et al. (2017) found through their analysis of USGS stream data from the greater Yellowstone area that there has been a substantial shift to earlier peak discharge events, reductions in summer minimum streamflow, and an overall reduction in stream discharge. Other studies conducted in the western U.S. have found similar trends as Al-Chokhachy et al. (2017). For example, Leppi et al. (2012) examined streamflow data from 153 streams across Montana, Idaho, and Wyoming, finding that over the last 50 years, 89% of them exhibited decreasing flows in the month of August, with the most drastic declines occurring in the last 8 to 10 years. Multiple studies conducted by Rood et al. (2008, 2005) found long-term declines in total stream discharge over the 20th century, with average declines ranging from 0.1% to 0.2% per year.

Isaak et al. (2012) found evidence for a shorter and more intense runoff cycle by focusing on trends in stream temperatures across the northwestern U.S. since 1980. One of their findings was that stream temperatures in the spring were getting colder, and the other three seasons—summer, fall, and winter—were getting warmer. To explain why spring flows were trending to colder than average temperatures, the authors suggested spring runoff is starting sooner and coming off with greater magnitude.

Finally, Al-Chokhachy et al. (2017) found increased variability in the timing of peak discharge since 1970, which strongly suggests there is more annual variability between drought years and flood years. All of these findings support our respondents' observations that runoff is: 1) starting earlier and ending earlier; 2) is more intense than before; and 3) is more variable between drought and flood years.

Yet respondents differed in points of reference to changes in runoff. For example, researchers and fisheries managers were aware of these changes, but their knowledge of these changes came largely from stream discharge data. Outfitters and guides differed in that their knowledge of these changes mostly came from personal experience. Outfitters and guides that had worked on the Yellowstone the longest described these changes with the most detail and told stories about their personal experiences with these changes. Outfitters and guides that have worked on the Yellowstone for shorter periods referred to either data and/or anecdotal stories from people who have more experience than them. However, no matter their frame of reference, respondents largely agreed that runoff has changed. Two respondents said they have not noticed any trends in the Yellowstone River's runoff cycle, and described the whole process as cyclical with drought and flood years occurring with no distinct direction. Besides these two, all other respondents had perceived, or were at least aware of these changes. This is notable because it indicates the magnitude and speed of these changes over the last 20–30 years.

5.2. Question 2: impacts from changing runoff

There are many factors related to shifting runoff cycles. Through our efforts, we found evidence that changes in runoff have affected river use and management in the following ways:

5.2.1. Uncertainty

Outfitters and guides indicated that yearly planning and booking has become more difficult because of increased runoff variability and the possibility of tough fishing conditions in August. We also heard the earlier and more intense runoff has made it more difficult for fisheries biologists/managers to conduct population estimates in the spring.

One outfitter said, "Conditions have become variable enough that we really need to make sure that our clients stay informed." However, there are challenges with trying to keep potential clients informed so they book trips or visit the Yellowstone during ideal conditions. For example, one respondent described that after consecutive drought years, clients become "gun-shy" about booking trips in August, even when conditions are expected to be good. Business in August of 2017 when fishing conditions were good suffered because the previous two years had poor August conditions. Flood years have also affected bookings. As one outfitter said about 2011, they were not "able to get on the river until almost the beginning of August because of a very heavy snow year." In 2011, trips scheduled in July had to be canceled or rescheduled because the water was too high to fish. To sum up the issue with variability, one outfitter said the following,

> It seems like, yeah, we have had a big water year, and then a few drought years, and now we have a huge snow pack this year (2017–2018 winter). So the thing is, somebody that came the 25th of June and probably had great fishing on the Yellowstone, Lord help the outfitter that tells them to come back the same time this year.

While outfitters and guides can do their best to inform client expectations, variable conditions are beyond their control and can lead to reduced certainty in future business. In addition, changes in runoff are affecting fisheries biologists/managers ability to collect data and track trends. Changes in runoff are also impacting the Yellowstone cutthroat trout, which we will cover in more detail in a subsequent Section (5.2.4).

5.2.2. Altered fishing conditions

The biggest impact we identified from an early runoff is that it often leads to low and warm flows in the later part of the summer, which adds stress to coldwater fish species and negatively affects fishing quality. As water temperatures reach or exceed 21 °C (70 °F), respondents said fishing slowed way down. In support of this, De Staso and Rahel (1994) found that Colorado River cutthroat trout (*Oncorhynchus clarkii pleuriticus*) changed their behavior and ate less frequently when water temperatures reached 20 °C, which would result in fish being more difficult to catch.

A large concern is that if these documented trends of earlier runoff, lower August flows, and warmer water temperatures continue (Al-Chokhachy et al., 2017; Isaak et al., 2012; Leppi et al., 2012; Rood et al., 2008, 2005), low and warm flows are going to become more common and more severe during August. According to Leppi et al. (2012), the trend of declining August flows has accelerated over the last decade. This trend will only continue to make fishing conditions more difficult in the late summer months. As one respondent said he used to tell people "put yourself in the middle of August for the good hopper fishing." However, with the recent trends in river conditions, he followed that statement with, "I would be a lot more cautious in giving that advice now."

In addition to low and warm flows making fishing more difficult, respondents also described increased use and changes in the aquatic insect population (covered in Section 5.2.3). Those with the most experience with the Yellowstone River described how fishing has become much more difficult over time. With increased use, and a higher probability of temperature and flow related fish stress, fishing on the Yellowstone may continue to become more difficult. At this point, it is unclear if this will affect the tourism industry surrounding the Yellowstone, but the combination of increasing use, tougher summer fishing conditions, and changes in aquatic insects will likely continue to make fishing more difficult on the Yellowstone River.

5.2.3. Changes in aquatic insect life

Many respondents identified changes in the aquatic macroinvertebrate population. The two main changes identified were: 1) reductions in overall abundance; and 2) changes in hatch timing. Respondents were able to provide a significant amount of descriptive detail with regards to species, timing, and their overall personal observations. Yet, even though respondents identified these trends widely, there is a lack of data or specific information about this seemingly well-known phenomenon.

Fisheries biologists were aware of these changes, but they had no data on which to base these personal observations. We do not mean to

imply causality, as we do not know if changes in runoff are causing these declines in species abundance or hatch timing. However, relationships between water temperature and changes in species abundance and richness have been found in previous research. For example, Durance and Ormerod (2007) looked at upland stream macroinvertebrate communities over a 25-year period (1981–2005). Accounting for the North Atlantic Oscillation's effects on temperature, they saw a 1.4–1.7 °C increase in stream temperature over the 25-year period. They also found that with every 1 °C increase in stream temperature, there was roughly a 21% decrease in spring macroinvertebrate abundance. These results align with respondent observations. Specifically, the reductions in abundance, as one outfitter said, "I wouldn't say they are gone, but they don't happen in the numbers that they used to." While data specific to the Yellowstone River are not available, the perceptions of respondents largely aligned with trends in other research and still has significant value.

The changes in macroinvertebrate abundance and timing seem to be having the largest impacts on fishing quality. Fisheries biologist/managers had no data to suggest the trout population in the Yellowstone is being affected. One biologist specifically stated the condition factor of trout has not changed, and the fish are still healthy. Some outfitters and guides did say they have notice changes in fish diets. They base this notion off of the contents in fish's stomachs (via stomach pumps) and how the tactics and flies they use to catch fish have changed over time. For example, one guide with 25 years of experience on the Yellowstone said fish seem to be eating a lot more midges than he remembers in the past. With population estimates become more difficult to conduct and angler catch rates going down (for various reasons), it may be difficult to fully understand how changes in macroinvertebrates will affect the Yellowstone River. Further research is needed to understand if/how macroinvertebrate populations are changing, what is causing the change, and how these changes affect the system as a whole.

5.2.4. Changes in species distribution

Another issue directly tied to changes in runoff and stream temperature is species distribution. Respondents identified two species that are experiencing changes in distribution: Yellowstone cutthroat trout (*Oncorhynchus clarkii bouvieri*) and smallmouth bass (*Micropterus dolomieu*). Cutthroat are moving farther upstream and are declining in numbers (Gresswell, 2011; Gunnell et al., 2008), while smallmouth bass are expanding their range and moving farther upstream (Ballard, 2017).

Yellowstone cutthroat trout are isolated from each other by a series of waterfalls on the Yellowstone River. The population has been declining above and below the waterfalls, but for slightly different reasons. Above the falls, declines in Yellowstone cutthroat trout have been attributed to predation by Lake trout (*Salvelinus naymaycrush*), overharvesting, whirling disease, and drought conditions (Koel et al., 2005). Respondents in this study—all of which are located below the waterfalls—mostly attributed declines to overharvesting in the 1970s and 1980s, competition between cutthroat and non-native gamefish like rainbow trout and brown trout, changes in hydrology and water temperature, and crossbreeding between cutthroat and rainbow trout.

Research has found stream temperatures are associated with the decreasing abundance of other coldwater fish species, like brown trout (*Salmo trutta*) (Hari et al., 2006). On a larger scale, Wenger et al. (2011) modeled how climate change will reduce the range of trout species, and projected that by the year 2080 trout will lose 47% of their habitat in the western U.S. (impact to specific species on the Yellowstone River: cutthroat trout (*Oncorhynchus clarkia*) 58% reduction; brown trout (*Salmo trutta)* 48% reduction; rainbow trout (*Oncorhynchus mykiss*) 35% reduction).

The crossbreeding between rainbow trout and cutthroat, which ultimately reduces the number of genetically pure cutthroat trout, is directly related to changes in runoff. Rainbow trout spawn on the ascending side of runoff and cutthroat spawn on the descending side, and as the runoff cycle is compressed into a shorter timeframe, there is an increased likelihood of the two species crossbreeding (Muhlfeld et al., 2009).

Another impact of the declining population is that the angler catch rate for Yellowstone cutthroat trout has been on a steep decline since the late 1990s, from around two fish per hour to less than one fish per hour (Koel et al., 2005). Although outfitters and guides in this study did not present a strong preference for one trout species over another, they noted that it had become more difficult to catch trout, and they were very concerned with the abundance of trout and the overall health of the Yellowstone ecosystem. Fisheries managers were, however, much more concerned with the decline in Yellowstone cutthroat trout because they are a native, iconic species that is experiencing rapid declines in abundance and range.

It was common knowledge among our respondents that smallmouth bass have been recently expanding their range in the Yellowstone River. One outfitter said, "Seems like there are more and more [smallmouth bass] every year. I caught more smallmouth bass in the sections I float this year than I ever have." The outfitting and guiding community has negative attitudes, or is even fearful, about smallmouth bass moving farther up the system. The main concern was the potential impacts bass could have on the Yellowstone River's trout population.

We asked outfitters and guides about the prospect of taking clients out to specifically target smallmouth bass, and they said there is very little demand for those kinds of trips. One said, "…people always have [smallmouth bass] in their program, but it's never popular because people are like: Montana, *A River Runs Through It* [movie reference], trout, you know." Another said, "People are here to catch trout, in particular, large trout" when we asked him about trying to sell smallmouth bass fishing trips on the Yellowstone.

Even though outfitters and guides were concerned about smallmouth bass, managers and researchers were not. They indicated smallmouth bass are considered a game species, are still far away from trout rearing areas, and that the upper Yellowstone River is bass free. When asked if smallmouth bass are having an impact on trout in the Yellowstone, one manager said,

> That's the piece that is kind of unknown right now. Clearly they are a top predator and like to eat smaller fish. They are pretty opportunistic feeders. We haven't seen anything, especially up here. The report of abundance is so low on bass that there really hasn't been much of an effect here. As you move down river there is quite a bit of overlap and bigger numbers, and as far as I know those guys aren't seeing any indication or trends at this point. They haven't seen an effect. There certainly could be, again, because they're a predator.

Fisheries managers and researchers pointed to smallmouth bass as an important sport fish in the lower reaches of the Yellowstone River around Billings, Montana. Given they are not seen as a threat, it is unlikely that any action will be taken to limit smallmouth bass until an issue is more explicitly identified. Even then, there will most likely be debate around potential actions given their value as a sport fish.

5.2.5. Disease outbreaks

The PKD outbreak in 2016 was a scary event for all the respondents. One outfitter said they "literally [saw] dead fish pretty much all the time." One of the reasons for closing the Yellowstone River after the PKD outbreak started was because there were concerns of spreading the parasite to other rivers (Opitz and Rhoten, 2017). However, since the outbreak the overall concern for PKD is much lower because of recent findings, such as: 1) PKD has been found in many Montana rivers and there have been no fish kills; 2) drought stress does not always cause a PKD outbreak; and 3) PKD has been in these systems for years, and is not a novel disease.

Researchers are currently investigating what causes PKD outbreaks, and why some outbreaks are more lethal than others. Given all of the recent discoveries about PKD, especially knowing PKD is largely present

throughout Montana and there are very few fish kills from it, future responses to a PKD outbreak will most likely be less severe than the response to the outbreak in 2016, which will greatly reduce the social and economic impacts that were previously experienced.

5.2.6. Imposed fishing regulations

Hoot-owl regulations are a direct management strategy aimed at reducing the impacts of drought conditions on fish. The impacts from the hoot-owl regulations themselves are relatively small. One guide said this when describing the impacts of the hoot-owl regulations, "The hoot-owls aren't terrible because people are still out here. Everyone just quits early and they are still out at the hotels and everything like that. They are still going to dinner." Outfitters and guides have been able to adapt to these regulations and work around them quite well, and there is actually a high level of support for the hoot-owl restrictions among the outfitter and guide community. However, when describing the river closure, this guide continued by saying when the "entire river is closed like last year, some of the best restaurants in town were just dead. The hotels were dead. That was different." The impacts from the full river closure were large. A report estimated that Park County, Montana—where the upper-Yellowstone River is located—lost between $359,750 to $523,815 USD of potential revenue during the 2016 river closure (Sage, 2016). At this time, it seems unlikely that future outbreaks of PKD, if/when they happen, will be met with such drastic actions as in 2016. Therefore, it is unlikely a full river closure—at least a PKD related closure—will happen in the future.

Collectively, our findings suggest outfitters, guides, and fisheries biologists/managers have been impacted by shifting runoff and altered temperatures. Outfitters and guides are struggling with increased uncertainty regarding runoff timing and the quality of fishing on the Yellowstone River; however, recreational use of the Yellowstone River continues to increase. There are also ecological changes occurring, such as declines in Yellowstone cutthroat trout and changes in aquatic macroinvertebrates.

One very important point that has not yet been mentioned is a challenge faced by fisheries biologists/managers, which is trying to collect more data to better monitor the resources they oversee. Since the outbreak, fisheries biologists and managers said they have been directed to collect more data—including game and non-game fish—so future changes can be better quantified. At the time of 2016 outbreak, no data was being collected on mountain whitefish, which made it impossible to determine the outbreak's ecological impact. This comes at a time when collecting their normal monitoring data is becoming more difficult. In addition, there is little to no data that our respondents were aware of which could be used to track or quantify seemingly massive changes in the Yellowstone River's macroinvertebrate population. Fisheries managers/biologist are constrained by time and resources to achieve all of these objectives, but given the changes that are projected, it is important to set a baseline for which future conditions can be compared.

5.3. Question 3: adaptation strategies

When the Yellowstone River and its tributaries are running low and warm, respondents described having to adapt to drought conditions. The strategies used by outfitters and guides to combat the effects of changing runoff cycles and drought events were: 1) altering catch-and-release practices; 2) temporally shifting trips; 3) spatially shifting trips; 4) drought anticipation; and 5) targeting warm water species. These adaptations have three underlying motivations, which are reducing economic losses, providing a quality fishing experience, and protecting fish populations. For example, when outfitters and guides alter their fishing practices when the water is warm they are trying to reduce the stress placed on fish as much as possible so they do not die after being released.

The main goal for shifting trips spatially and/or temporally is to find colder water temperatures to reduce stress on fish and provide clients a quality experience. Guiding during times, or in places, with colder water also decreased the chances of released fish mortality, but it also offers clients opportunities to pursue fish that are not stressed, which generally means they are more likely to take an angler's fly or lure. The combination of all of these factors create a higher quality experience for clients while also reducing resource impacts.

Drought anticipation was also motivated by resource protection and providing a quality experience. Only one outfitter we spoke with heavily relied on the method of assessing snowpack and strategically booking trips around an anticipated early runoff and August fishing restrictions. This strategy was quite effective, and from our conversations, seemed to be associated with relatively small economic losses. However, this outfitter did not own a fly shop, so he was not impacted by the reduction of in-store sales. People with fly shops tended to be hit harder because they were not able to pack up and move and work on a different river. They were able to send their guides to other rivers, but the revenue generated by in-store sales crashed during the closure. Shop owners also have more overhead, which made the closure harder on them. To reduce economic impacts, provide a quality fishing experience, and protect fish populations, most outfitters and guides use a combination of these strategies to make it through drought events.

Targeting warm water species, although it seems like a logical strategy when drought conditions make trout fishing suboptimal, is not commonly used by outfitters and guides. They described their willingness to target warm-water species, but they also said there is very little interest from clients. Many respondents said something to the effect of 'people come to Montana to fish for trout.' It does seem like there has been an increase in interest to target warm-water species like smallmouth bass and/or carp with a fly, but from our conversations with the outfitter and guide community, this does not seem to be an effective adaptation because there is a lack of interest from the majority of clients.

Overall, outfitters and guides have adopted several strategies to adjust to changing river conditions. The three main motivations for these adaptations were reducing economic losses, providing a quality fishing experience, and protecting fish populations. Outfitters and guides expressed a deep desire to protect the Yellowstone River and the fishery. They were largely aware of their own impacts and altered their practices to reduce these impacts as much as possible. From our conversations, it seems outfitters and guides have largely been able to adapt to these changes, and create a balance between business and resource protection.

One final point to make here is about displacement. We framed our conversations around *adaptations to shifting conditions*, but some elements of displacement arose during our conversations. Displacement in the outdoor recreation literature is often defined as "a behavioral coping mechanism in that it involves spatial or temporal changes in use patterns" (Manning 1999, p. 95). The vast majority of research around displacement has focused on social factors like crowding (e.g., Robertson and Ragula, 1994), where visitors are dissatisfied or overwhelmed with the amount of other people in an area so they: 1) move to another site; 2) move to a different area all together; or 3) shift when they visit to avoid crowds (Manning, 1999). Some research has attributed displacement to environmental impacts from human use (e.g., Anderson, 1980, 1983; Anderson and Brown, 1984).

In our conversations, there were two elements of displacement. First, all respondents mentioned the ever increasing number of people fishing and floating the Yellowstone River, and how this has decreased the quality of experience and quality of fishing. Since the focus of this study was on shifting runoff, we largely excluded this theme. The second element of displacement was changing behaviors to avoid, in a broad sense, climate impacts. In both cases, respondents described altering their behavior to find quality experiences, whether that be fewer people, better fishing, or cooler water. An area of future research could be how *anglers* are responding to these social and environmental

changes, specifically if and how displacement is occurring.

This poses another question: what are the ecological consequences of spatial displacement/adaptation? Respondents mentioned shifting higher into the Yellowstone watershed to find cooler water. This potentially places more use in the upper reaches of the watershed, which hold many of the remaining healthy Yellowstone cutthroat populations. Therefore, if people are 'chasing' cooler water and moving into these areas, what might the impacts be for these smaller, predominately cutthroat filled waters?

6. Limitations

Several limitations of this study should be noted. First, we were working with a small sample size, which can be problematic given the extent of the Yellowstone River and the variety of stakeholders and interests involved. However, given our focus (looking at the perceptions and impacts of changing hydrology and the adaptations used by the outfitting and guiding industry), the population of interest was relatively small, and we contacted all respondents that were provided to us. Also, we reached theoretical saturation because toward the end of the interview process we continued to hear the same themes, and no new information was being provided.

In qualitative data collection, there is also an inherent balance between sample size and depth of the interview. Because we were using an inductive approach and working with a relatively small population, we were able to explore more concepts and in greater depth given our ability to devote more time to individual interviews. The length and detail of each interview, if expanded to additional participants, would likely have prohibited our ability not only to conduct a large number of interviews if more potential participants could have been identified, but also the effectiveness of our analysis in winnowing a larger dataset to meaningful and relevant themes.

7. Future research

This study focused on the most knowledgeable and experienced people we could find to shed light on the following questions: Are people perceiving changes in runoff; are there impacts from shifting runoff; and what adaptations are being used. We found this particular collection of 'experts' perceived changes, are being impacted by these changes, and are trying to adapt to them. The next logical questions is to see if the broader angling community is noticing these shifts in runoff, are being impacted by these shifts, and are employing adaptation strategies to manage them. There is also the question of whether anglers are being displaced by these shifts in runoff. If they are, where are they going and can these places handle increased use? In addition, there is the question of whether the general angling public is concerned about high water temperatures, the impacts to fish, and are these anglers altering their angling practices to reduce their impacts during stressful conditions like outfitters and guides are.

The Yellowstone is a large, relatively unaltered, wild river. Given this, it is most likely affected differently from shifts in runoff than other more managed river systems. Are managed systems more or less resilient to shifting runoff than unmanaged systems? Multiple respondents described moving their guiding operations to the Big Horn River, which is dammed. An interesting comparison study could help give direction on where to focus angling attention during stressful conditions.

8. Conclusion

Runoff cycles are shifting throughout the western U.S., with widespread and varied social and ecological effects. The purpose of this study was to document if people perceived changes in runoff, if/how changing runoff has affected the social and ecological components of the Yellowstone River, and if/how people are adapting to the challenges associated with drought conditions and changes in runoff. We were able to identify that: 1) people are perceiving the recent shifts in hydrology (i.e., earlier runoff, shorter and more intense runoff, increased annual variability, and warmer water temperatures); 2) there are social and ecological impacts from these shifts; and 3) people are employing strategies to help them cope with these changes. We were also able to corroborate the information we gathered from our interviews with information documented in peer-reviewed scientific literature. Respondents said fishing on the Yellowstone is still good, and that the effects of shifting runoff have thus far been manageable. But if trends continue, and drought conditions become more frequent and severe, that might not hold for the future.

Recreational use of the Yellowstone River has been increasing sharply over the last decade, and lower flows and higher temperatures are affecting the resource and, at times, the angling experience. Although these changes are gradual, they are occurring, and many a little faster than most of us want to believe, as one outfitter said,

> Twenty years ago I kind of looked at [climate change] and thought, boy, if I had grandkids, I'd be a little bit worried about how it's really going to change the fishing. Now, it's like screw the grandkids, it's like what is happening to me! It really seemed like a lot of this would be slow incremental changes that probably really won't notice that big of a change from now until I am done fishing, but the next couple of generations really will, and boy, it seems like the changes have come much faster than I have ever imagined.

CRediT authorship contribution statement

Chase C. Lamborn: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing - original draft. **Jordan W. Smith:** Conceptualization, Methodology, Resources, Writing - review & editing, Supervision, Project administration, Funding acquisition.

Acknowledgements

This research was funded by the Institute of Outdoor Recreation and Tourism at Utah State University. The authors would like to thank Brooke Sausser for reviewing an earlier version of the manuscript

References

Al-Chokhachy, R., Sepulveda, A.J., Ray, A.M., Thoma, D.P., Tercek, M.T., 2017. Evaluating species-specific changes in hydrologic regimes: an iterative approach for salmonids in the Greater Yellowstone Area (USA). Rev. Fish Biol. Fish. 27 (2), 425–441. https://doi.org/10.1007/s11160-017-9472-3.

Anderson, D., 1980. Long-time Boundary Waters' visitors change use patterns. Naturalist 31, 2–5.

Anderson, D., 1983. Displacement: one consequence of not meeting people's needs. In: Harris, H.M., Spearing, A.M. (Eds.), Research in Forest Productivity, Use, and Pest Control (General Technical Report NE-90). USDA Forest Service, Northeastern Research Station.

Anderson, D., Brown, P., 1984. The displacement process in recreation. J. Leis. Res. 16, 61–73.

Ballard, J., 2017. Eyeing the new neighbors: Smallmouth bass are moving upstream on the Yellowstone. Will they harm the river's renowned trout population? Montana Outdoors 11–13.

Bartholomew, A., Bohnsack, J.A., 2005. A review of catch-and-release angling mortality with implications for no-take reserves. Rev. Fish Biol. Fish. 15 (1), 129–154. https://doi.org/10.1007/s11160-005-2175-1.

Buisson, L., Thuiller, W., Lek, S., Lim, P., Grenouillet, G., 2008. Climate change hastens the turnover of stream fish assemblages. Glob. Change Biol. 14 (10), 2232–2248. https://doi.org/10.1111/j.1365-2486.2008.01657.x.

Byron, E., 2016. After Thousands of Fish Die in the Yellowstone River, Officials Lift Boating Bans. Retrieved 21 January 2019, from. https://www.hcn.org/articles/after-thousands-of-fish-die-in-the-yellowstone-river-officials-lift-boating-bans.

Corbin, J.M., Strauss, A.C., 2008. Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory, 3rd ed. Sage, Thousand Oaks, CA.

Creswell, J.W., 2013. Five qualitative traditions of inquiry. Qualitative Inquiry and Research Design: Choosing Among Five Approaches, 3rd ed. Sage, Thousand Oaks, CA, pp. 69–110.

De Staso, J., Rahel, F.J., 1994. Influence of water temperature on interactions between juvenile Colorado river cutthroat trout and brook trout in a laboratory stream. Trans. Am. Fish. Soc. 123 (3), 289–297. https://doi.org/10.1577/1548-8659(1994)123<0289:IOWTOI>2.3.CO;2.

Dettinger, M.D., Cayan, D.R., 1995. Large-scale atmospheric forcing of recent trends toward early snowmelt runoff in California. J. Clim. 8 (3), 606–623. https://doi.org/10.1175/1520-0442(1995)008<0606:LSAFOR>2.0.CO;2.

Durance, I., Ormerod, S.J., 2007. Climate change effects on upland stream macroinvertebrates over a 25-year period. Glob. Change Biol. 13 (5), 942–957. https://doi.org/10.1111/j.1365-2486.2007.01340.x.

Ebersole, J.L., Liss, W.J., Frissell, C.A., 2003. Thermal heterogeneity, stream channel morphology, and salmonid abundance in northeastern Oregon streams. Can. J. Fish. Aquat. Sci. 60 (10), 1266–1280. https://doi.org/10.1139/f03-107.

Ficke, A.D., Myrick, C.A., Hansen, L.J., 2007. Potential impacts of global climate change on freshwater fisheries. Rev. Fish Biol. Fish. 17 (4), 581–613. https://doi.org/10.1007/s11160-007-9059-5.

Gresswell, R.E., 2011. Biology, status, and management of the Yellowstone cutthroat trout. N. Am. J. Fish. Manag. 31 (5), 782–812. https://doi.org/10.1080/02755947.2011.608980.

Gunnell, K., Tada, M.K., Hawthorne, F.A., Keeley, E.R., Ptacek, M.B., 2008. Geographic patterns of introgressive hybridization between native Yellowstone cutthroat trout (Oncorhynchus clarkii bouvieri) and introduced rainbow trout (O. mykiss) in the South Fork of the Snake River watershed, Idaho. Conserv. Genet. 9 (1), 49–64. https://doi.org/10.1007/s10592-007-9302-6.

Hari, R.E., Livingstone, D.M., Siber, R., Burkhardt-Holm, P., Güttinger, H., 2006. Consequences of climatic change for water temperature and brown trout populations in Alpine rivers and streams. Glob. Change Biol. 12 (1), 10–26. https://doi.org/10.1111/j.1365-2486.2005.001051.x.

Hunt, L.M., Fenichel, E.P., Fulton, D.C., Mendelsohn, R., Smith, J.W., Tunney, T.D., et al., 2016. Identifying alternative pathways for climate change to impact inland recreational fishers. Fisheries 41 (7), 362–372.

Intergovernmental Panel on Climate Change, 2014. AR5 Synthesis Report: Climate Change 2014 — IPCC. Retrieved 21 January 2019, from. . https://www.ipcc.ch/report/ar5/syr/.

Isaak, D.J., Wollrab, S., Horan, D., Chandler, G., 2012. Climate change effects on stream and river temperatures across the northwest U.S. From 1980–2009 and implications for salmonid fishes. Clim. Change 113 (2), 499–524. https://doi.org/10.1007/s10584-011-0326-z.

Jones, R., Travers, C., Rodgers, C., Lazar, B., English, E., Lipton, J., et al., 2013. Climate change impacts on freshwater recreational fishing in the United States. Mitig. Adapt. Strateg. Glob. Change 18 (6), 731–758. https://doi.org/10.1007/s11027-012-9385-3.

Karr, J.R., 1991. Biological integrity: a long-neglected aspect of water resource management. Ecol. Appl. 1 (1), 66–84. https://doi.org/10.2307/1941848.

Koel, T.M., Bigelow, P.E., Doepke, P.D., Ertel, B.D., Mahony, D.L., 2005. Nonnative lake trout result in Yellowstone cutthroat trout decline and impacts to bears and anglers. Fisheries 30 (11), 10–19. https://doi.org/10.1577/1548-8446(2005)30[10:NLTRIY]2.0.CO;2.

Leppi, J.C., DeLuca, T.H., Harrar, S.W., Running, S.W., 2012. Impacts of climate change on August stream discharge in the Central-Rocky Mountains. Clim. Change 112 (3), 997–1014. https://doi.org/10.1007/s10584-011-0235-1.

Lessard, J.L., Hayes, D.B., 2003. Effects of elevated water temperature on fish and macroinvertebrate communities below small dams. River Res. Appl. 19 (7), 721–732. https://doi.org/10.1002/rra.713.

Lettenmaier, D.P., Wood, E.F., Wallis, J.R., 1994. Hydro-climatological trends in the continental United States, 1948–88. J. Clim. 7 (4), 586–607. https://doi.org/10.1175/1520-0442(1994)007<0586:HCTITC>2.0.CO;2.

Manning, R., 1999. Studies in Outdoor Recreation. Oregon State University Press, Corvallis, OR.

Moustakas, C., 1994. Phenomenological Research Methods. Sage, Thousand Oaks, CA.

Muhlfeld, C.C., McMahon, T.E., Belcer, D., Kershner, J.L., 2009. Spatial and temporal spawning dynamics of native westslope cutthroat trout, Oncorhynchus clarkii lewisi, introduced rainbow trout, Oncorhynchus mykiss, and their hybrids. Can. J. Fish. Aquat. Sci. 66 (7), 1153–1168. https://doi.org/10.1139/F09-073.

Neuheimer, A.B., Taggart, C.T., 2007. The growing degree-day and fish size-at-age: the overlooked metric. Can. J. Fish. Aquat. Sci. 64 (2), 375–385. https://doi.org/10.1139/f07-003.

Opitz, S., Rhoten, J., 2017. 2016 Mountain Whitefish Kill on the Yellowstone River. Retrieved from. Montana Fish, Wildlife, and Parks, pp. 34. http://mtflyfishmag.com/wp-content/uploads/2018/03/2016-Mountain-Whitefish-Kill-on-the-Yellowstone-River-Finalx.pdf.

Poff, N.L., Ward, J.V., 1989. Implications of streamflow variability and predictability for lotic community structure: a regional analysis of streamflow patterns. Can. J. Fish. Aquat. Sci. 46 (10), 1805–1818. https://doi.org/10.1139/f89-228.

Poff, N.L., Allan, J.D., Bain, M.B., Karr, J.R., Prestegaard, K.L., Richter, B.D., et al., 1997. The natural flow regime. BioScience 47 (11), 769–784. https://doi.org/10.2307/1313099.

Pörtner, H.O., Farrell, A.P., 2008. Physiology and climate change. Science 322 (5902), 690–692. https://doi.org/10.1126/science.1163156.

Pörtner, H.O., Bock, C., Knust, R., Lannig, G., Lucassen, M., Mark, F.C., Sartoris, F.J., 2008. Cod and climate in a latitudinal cline: physiological analyses of climate effects in marine fishes. Clim. Res. 37 (2–3), 253–270. https://doi.org/10.3354/cr00766.

Robertson, R., Ragula, J., 1994. Recreational displacement and overall satisfaction: a study of central Iowa's licensed boaters. J. Leis. Res. 26, 174–181.

Rood, S.B., Samuelson, G.M., Weber, J.K., Wywrot, K.A., 2005. Twentieth-century decline in streamflows from the hydrographic apex of North America. J. Hydrol. 306 (1–4), 215–233. https://doi.org/10.1016/j.jhydrol.2004.09.010.

Rood, S.B., Pan, J., Gill, K.M., Franks, C.G., Samuelson, G.M., Shepherd, A., 2008. Declining summer flows of Rocky Mountain rivers: changing seasonal hydrology and probable impacts on floodplain forests. J. Hydrol. 349 (3), 397–410. https://doi.org/10.1016/j.jhydrol.2007.11.012.

Sage, J.L., 2016. Economic Contributions of the Yellowstone River to Park County, Montana. Retrieved from. Institute for Tourism and Recreation, Missoula, MT. https://scholarworks.umt.edu/itrr_pubs/346.

Sloat, M.R., Osterback, A.-M.K., 2013. Maximum stream temperature and the occurrence, abundance, and behavior of steelhead trout (Oncorhynchus mykiss) in a southern California stream. Can. J. Fish. Aquat. Sci. 70 (1), 64–73. https://doi.org/10.1139/cjfas-2012-0228.

Stewart, I.T., Cayan, D.R., Dettinger, M.D., 2004. Changes in snowmelt runoff timing in western North America under a "business as usual" climate change scenario. Clim. Change 62 (1–3), 217–232. https://doi.org/10.1023/B:CLIM.0000013702.22656.e8.

Stewart, I.T., Cayan, D.R., Dettinger, M.D., 2005. Changes toward earlier streamflow timing across Western North America. J. Clim. 18 (8), 1136–1155. https://doi.org/10.1175/JCLI3321.1.

Takasuka, A., Oozeki, Y., Aoki, I., 2007. Optimal growth temperature hypothesis: Why do anchovy flourish and sardine collapse or vice versa under the same ocean regime? Can. J. Fish. Aquat. Sci. 64 (5), 768–776. https://doi.org/10.1139/f07-052.

Wenger, S.J., Isaak, D.J., Luce, C.H., Neville, H.M., Fausch, K.D., Dunham, J.B., et al., 2011. Flow regime, temperature, and biotic interactions drive differential declines of trout species under climate change. Proc. Natl. Acad. Sci. U. S. A. 108 (34), 14175–14180. https://doi.org/10.1073/pnas.1103097108.